DTIC FILE COPY

# ...TION PAGE

Form Approved
OMB No. 0704-0188

AD-A223 439

...rage 1 hour per response, including the time for reviewing instructions, searching existing data sources, ...e collection of information. Send comments regarding this burden estimate or any other aspect of this ... Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson ...anagement and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE
March 31, 1990

3. REPORT TYPE AND DATES COVERED
Final. 1.12.88-...11...

4. TITLE AND SUBTITLE
Atmospheric Structure and Variability

5. FUNDING NUMBERS
... - FA86...-88-C-...

6. AUTHOR(S)
... Rees and T.J. Fuller-Rowell

DTIC ELECTE JUN 15 1990 S D D

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
University College London
Gower Street
London WC1E 6BT
United Kingdom

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Sponsoring Agency: Air Force Office of Scientific Research, Bolling AFB, DC 20332-6448

Sponsoring/Monitoring Agency: European Office of Aerospace Research & Development, Box 14, FPO, New York 09510-0200

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
TR-90-07

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release;
distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

The contract has supported an extensive programme of atmospheric and ionospheric modelling, aimed at examining Atmospheric Structure and Variability, using the CRAY XMP-48 at the Rutherford Appleton Laboratory and the CRAY 2S machines at the University of London Computing Centre, part of the programme of atmospheric physics research activities of the Atmospheric Physics Laboratory. A technique of forcing tidal and other natural atmospheric fluctuations at the lower boundary of the present version of the 3-dimensional, time-dependent global thermosphere-ionosphere model has been developed. Also, a series of numerical studies have been carried out into the modelled response of the thermosphere during a series of geomagnetic storms in 1981 and 1982, observed by the NASA Dynamics Explorer-2 spacecraft. Further studies have concentrated on using these models for studies of thermosphere - ionosphere coupling, atmospheric density, lower atmospheric tides, participation in the analysis and interpretation of empirical data obtained during the 'Lower Thermosphere Coupling Study', the mid- and low-latitude ionospheric effects of geomagnetic storms, and for studies of the solar activity and geomagnetic activity causes of variations of lower thermospheric atomic oxygen and nitric oxide densities.

14. SUBJECT TERMS
(Key words): Atmospheric density, Atmospheric tides, Ionosphere-thermosphere coupling, Geomagnetic storm effects, Atomic oxygen, nitric oxide,

15. NUMBER OF PAGES

16. PRICE CODE

| 17. SECURITY CLASSIFICATION OF REPORT | 18. SECURITY CLASSIFICATION OF THIS PAGE | 19. SECURITY CLASSIFICATION OF ABSTRACT | 20. LIMITATION OF ABSTRACT |
|---|---|---|---|
| UNCLASSIFIED | UNCLASSIFIED | UNCLASSIFIED | UL |

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18

Great Britain

90 06 14 124

BEST AVAILABLE COPY

ATMOSPHERIC PHYSICS LABORATORY

DEPARTMENT OF PHYSICS AND ASTRONOMY
UNIVERSITY COLLEGE LONDON

Final Contract Report for USAF / EOARD / AFOSR, March 1990.

Ref: F49620-87-C-0096

# "Atmospheric Structure and Variability."

David Rees and Timothy J. Fuller Rowell.

March 1990.

## SUMMARY

An extensive programme of atmospheric and ionospheric modelling, aimed at examining "Atmospheric Structure and Variability", using the CRAY XMP-48 at the Rutherford Appleton Laboratory and the CRAY 2S machines at the University of London Computing Centre has been carried out as part of the atmospheric physics research programme of the Atmospheric Physics Laboratory. A summary of our major projects, highlighting the recent research achievements and publications, is given below. There have been two major thrusts of the work in progress under this contract.

Firstly, the development of a technique of forcing tidal and other natural atmospheric fluctuations at the lower boundary of the present version of the 3-dimensional, time-dependent global thermosphere-ionosphere model. This improves the simulation of the behaviour of structure and variability within the upper mesosphere and lower thermosphere. With this tidal model it is possible to intercompare the model results with data from ground-based instruments, such as the incoherent scatter and M.S. radars and Fabry-Perot interferometers.

Secondly, a series of numerical studies have been carried out into the modelled response of the thermosphere during a series of geomagnetic storms in 1981 and 1982. These storms were well-observed by the NASA Dynamics Explorer-2 spacecraft, and it has been possible to carefully compare the series of model simulations, using various parameterised drivers representing geomagnetic variability. The response of the upper thermosphere to geomagnetic activity is one of the major causes of density temperature and wind variability. The most appropriate index of activity is quite central to improving the modelling, using empirical or theoretical models. We have shown that the difference between the time-dependence of available indices is quite critical for accurate modelling, so that there is as large a difference between model results using different available indices, as between any of the storm simulations and data from Dynamics Explorer. Investigation of the causal physics via the combination of observations (i.e. DE, and UARS and other future missions) and simulations using the present coupled ionosphere-thermosphere models, will improve our understanding of how to best combine the available information on thermosphere / ionosphere drivers. We expect this to lead to improved indexing of both the empirical and theoretical models to geomagnetic activity.

The large time allocations made available on the UK CRAY machines have been effectively used to implement our theoretical and numerical modelling research programme during the past 2 years. This work has been primarily concerned with the extended development of the UCL / Sheffield coupled model of the neutral thermosphere and ionosphere. This has involved the integration of the University

College London neutral atmosphere code, designed to model the energy budget, dynamics, and composition of the earth's upper atmosphere, with the Sheffield University high-latitude ionospheric model. The latter model includes the effects of magnetospheric plasma convection, energetic particle precipitation and photoionisation. The coupled model is able to self-consistently simulate the variety of complex interactions between the neutral and plasma environments. This enables us to examine the importance and relevance of the different processes, and to evaluate their individual roles in producing observed phenomena. The ionospheric code has recently been extended to cover mid and low latitude regions. We have run the combined model on the CRAY machines and have made a number of significant advances in the subject during the past 2 - 3 years.

## RECENT PROGRESS

Significant progress has been made in the two major aspects of the modelling work:

Firstly, there are the interactions with tidal, planetary and gravity waves emanating from the lower and middle atmosphere, which primarily affect the lower boundary conditions and the structure and dynamics of the lower thermosphere. With the current model, we can now intercompare results from the incoherent scatter radars and new generation ground-based FPIs, this has lead to a number of papers now in press and in preparation. The empirical studies show, very convincingly, the day to day variability of the tidal and gravity wave forcing of the lower thermosphere via troposphere / stratosphere sources, providing a new challenge for the extended development of the numerical codes.

Secondly, we have continued studying the interactions between the magnetosphere and the polar ionosphere, through the medium of the polar electric field, and the magnetospheric field-aligned current system, with charge carriers including the energetic particles which excite the auroral ionosphere and auroral emissions. The first experiments with the Rice University Group have now been performed, interchanging model results, so that we can examine the nature of interactions, ahead of fully-coupling the two numerical codes. Even the present computing machines have a critical limitation in the core and speed requirements for such a task. However, new machines, expected to be available for 'pump-priming' by mid 1990, will be able to run such complex tasks as a fully-interactive magnetosphere-ionosphere-thermosphere model. We anticipate that this activity will lead to improved understanding of the relationship between the actual magnetospheric sources of energy and momentum, their coupling to, and sinks within the thermosphere, and the various feed-back processes. We also hope that this work will lead to a deeper understanding of the physical processes behind the available indices of global geomagnetic activity and solar wind parameters, which will aid future predictive modelling of the ionosphere-thermosphere system and its response to solar and geomagnetic variability.

### I. Thermosphere/Ionosphere coupling.

Simulations, by the coupled thermosphere/ionosphere model, for the December and June solstices have shown perhaps the most striking interactions between the neutral and ionised components. The model has shown that in the summer polar regions, the upper thermosphere neutral gas composition has a very strong control on the plasma density /1/. This strong control was not apparent when using recent empirical models of neutral composition such as MSIS 1986. Comparison of the seasonal variation of plasma density, as observed by the European Incoherent Scatter Radar facility (EISCAT) in northern Scandinavia, now shows good agreement with the simulations /2/. The model now enables us to understand relative importance of the different major processes which are involved.

The simulations of the electrodynamics of the lower thermosphere at high latitudes are now realistic, enabling the model to be used to test the various empirical descriptions of the magnetospheric energy, momentum and precipitation inputs /3/, which are some of the main drivers of the upper atmosphere. In addition, the simulated neutral circulation in the lower thermosphere at high latitudes in these self-consistent calculations is much closer to observations /4,5/.

During equinox and at winter solstice, transport of plasma by the convective electric field has a major influence on the structure of the high latitude ionosphere. The numerical model has been used to isolate the influence and respective contributions of the polar convective electric field and auroral precipitation in determining the structure of the ionospheric F-region, and in the creation of the trough features on the equatorward edge of the auroral oval /6/.

## II. Atmospheric Density.

The coupled numerical model provides a more accurate means of computing the response of the density of the upper atmosphere to changes in solar radiation, the magnetospheric input, and from tides propagating from the lower thermosphere. An accurate knowledge of the mass density is necessary for accurate prediction of the location and lifetimes of earth orbiting satellites. Simulations have been performed comparing the various available indices of geomagnetic and auroral activity. These indices describe the magnetospheric input in three distinct ways /7/. The results indicate that prediction of small scale and short period variations requires considerably improved empirical data to describe the geomagnetic inputs and their variations.

## III. Atmospheric Tides.

A major driver of the mid and low latitude thermosphere is the tidal energy propagating upwards from sources in the lower atmosphere. The thermosphere is slow to respond to this forcing (5 to 10 days), requiring long, time-consuming, computation. Numerical simulations of the seasonal response to propagating tides indicates that the magnitudes and phases of propagating tides at the base of the thermosphere are quite variable. This variable forcing is required to match empirical data obtained from different locations and observing periods /8,9/. We have recently demonstrated that, with our new Fabry-Perot interferometer installed at the Utah State University Hardware Ranch Facility at Bear Lake, Utah, we can obtain very high quality data on tidal wind components around 86 km altitude, using the Meinel band emissions at 843 nm /10/. These continuing tidal wind studies, combining new empirical and model studies, are described further in Annex 1.

## IV. Lower Thermosphere Coupling Study

Comparisons have been made of the model prediction of the lower thermosphere neutral wind and temperature and ion temperature with Incoherent Scatter observations for the September 1987 Lower Thermosphere Coupling Study /9/.

The results indicate that symmetric (2,2) and (2,4) global Hough modes can reproduce the vertical structure of the observations at high and mid-latitude provided amplitude significantly larger than linear model predictions are used. The simulations also show that at high latitudes the semi-diurnal response in ion temperature is driven primarily by geomagnetic processes, rather than tides, and that a large difference in the ion and neutral temperature penetrates down to 110 km altitude during active conditions.

V. Geomagnetic Storm Effects

Observations from mid-latitude ionosondes indicate that the F2 layer electron density is depleted during and following a geomagnetic storm. The 'negative' storm phenomenon is a complex and important consequence of geomagnetic storms and affects global radio communications. The coupled model has been used to assess the consequences of a possible storm-time heat source resulting from energetic ion precipitation from the ring current. It was shown that such an additional source could appreciably change the neutral composition, enhancing the F2 region depletion /11/.

Recent simulations with the coupled thermosphere ionosphere model have been able to reproduce the seasonal and local time response of thermospheric composition to storm-time magnetospheric input /12/. The storm-time model simulations reproduce the penetration to low latitudes of a region of increased molecular nitrogen density in the early morning sector of the summer hemisphere. These changes qualitatively reproduce the observed depletions in the F2-region ionosphere expected as the result of an increase in mean molecular mass.

VI. Atomic oxygen and nitric oxide.

Using an advanced version of a 2-Dimensional global model, which includes a more comprehensive photo-chemical code than the 3-D model, it has been possible to study the global distribution of atomic oxygen and nitric oxide as a function of season, latitude and geomagnetic activity /13/. The data recently published on nitric oxide distributions and variability from SME satellite observations by Barth (1988) and Siskind et al (1989) has provided an excellent test of the model, and an opportunity to use the model to test the key branching ratios involved in the photochemical production processes, and the wide range of atmospheric processes involved in the generation, distribution and destruction of nitric oxide, and its implications for the distribution of other key minor constituents, including mesospheric ozone.

VII. Review papers.

Results from the studies carried out under the support from this contract have been used in a number of other invited review papers presented in recent international conferences (AGARD, Chapman 'Auroral Physics' Conference in Cambridge, July 1988, COSPAR (July 1988, NATO (Sept 1988, Moscow (Jan 1989), ESA /ESTEC (May 1989) and IAGA, Exeter, July 1989, /12-22/.

VIII. Other Work.

The UCL / Sheffield Model has been used in conjunction with the interpretation of data obtained during a number of coordinated ground-based programmes within WITS, such at GITCAD, LTCS, ETC. Approximately 10 papers have been recently published or are in press describing the results of these joint programmes and studies.

References.

1. Rees D., T.J. Fuller-Rowell, S. Quegan, R.J. Moffett, and G.J. Bailey. Simulations of the seasonal variations of the thermosphere and ionosphere using a coupled, three-dimensional, global model, including variations of the interplanetary magnetic field. J. Atmos. Terr. Phys., Vol.50, No. 10/11, 903-930, 1988.

2. Farmer A.D. and T.J. Fuller-Rowell. Comparing numerical simulations of the high latitude ionosphere to an empirical mean model based on EISCAT data. Adv. Space Res., Vol.10, No. 6, (6)143-(6)148, 1988.

3. Fuller-Rowell T.J.. Model simulations of the electrodynamics of the high-latitude thermosphere and ionosphere with the magnetospheric input defined by statistical or empirical models. Adv. Space Res., Vol.10, No. 6, (6)153-(6)165, 1988.

4. Rees D. and T.J. Fuller-Rowell. Modelling the E-region auroral winds. Adv. Space Res., Vol.10, No. 6, (6)197-(6)213, 1988.

5. Killeen T.L., B. Nardi, F.G. McCormac, J.W. Meriwether, J.P. Thayer, R.G. Roble, T.J. Fuller-Rowell, and D. Rees. Lower thermosphere structure and dynamics inferred from satellite and ground-based Fabry-Perot observations of the $O(^1S)$ green line emission. Adv. Space Res., submitted 1988.

6. Fuller-Rowell T.J., D. Rees, S. Quegan, and R.J. Moffett, Numerical simulations of the sub-auroral trough. J. Atmos. Terr. Phys. Special issue, 1990, proceeding of the IAGA meeting in Exeter, July 1989.

7. Rees D. and T.J. Fuller-Rowell. Numerical computations of thermospheric density, using coupled ionosphere / thermosphere codes and parameterised solar and geomagnetic input. Proceeding of Thermospheric Density Workshop, AFGL, October 22-24, 1987.

8. Parish H., T.J. Fuller-Rowell, D. Rees, T.S. Virdi, and P.J.S Williams. Numerical simulations of the seasonal response of the thermosphere to propagating tides. Adv. Space Res., Vol.10, No. 6 (6)287-(6)291, 1988.

9. Fuller-Rowell T.J., D. Rees, H.F. Parish, T.S. Virdi, P.J.S. Williams and R.G. Johnson. Lower Thermosphere Coupling Study: Comparison of Observations with Predictions of the UCL-Sheffield Thermosphere-Ionosphere Model. (In press) 1990.

10. Rees D., V.B. Wickwar, R.J. Sica, A. Aruliah and T.J. Fuller-Rowell. Winds in the Upper Mesosphere at mid-latitude: First Results using an Imaging Fabry-Perot Interferometer. Geophys. Res. Lett. (in press) 1990.

11. Fuller-Rowell T.J., D. Rees, B.A. Tinsley, H. Rishbeth, A.S. Rodger, and S. Quegan. Modelling the response of the thermosphere and ionosphere to geomagnetic storms : effects of a midlatitude heat source. Adv. Space Res., Vol.10, No. 6, (6)215-(6)223, 1988.

12. Fuller-Rowell T.J., D. Rees, H. Rishbeth, A.G. Burns, Killeen T.L. and R.G. Roble, Modelling of Compositional changes during F-region Storms. J. Atmos. Terr. Phys. Special Issue, 1990, proceeding of the IAGA meeting in Exeter, July 1989.

13. Rees D. and T.J. Fuller-Rowell. Numerical simulations of the seasonal / latitudinal variations of atomic oxygen and nitric oxide in the lower thermosphere and mesosphere, Adv. Space Res., Vol.10, No. 6, (6)83-(6)102, 1988.

14. Rees D. and T.J. Fuller-Rowell. The response of the thermosphere and ionosphere to magnetospheric forcing. Proceedings of the Royal Society Discussion Meeting: "The Magnetosphere, the High Latitude Ionosphere, and their Interactions", London, May 11-12th, 1988, Phil. Tran. R. Soc. London, A328, 139-171, 1989.

15. Rees D. and T.J. Fuller-Rowell. Seasonal and universal time variations of the geomagnetic response of the thermosphere and ionosphere. Proceedings of the AGARD/NATO Symposium on "Ionospheric / Atmospheric Interactions", Munich, May 16-20, 1988, p.21-27.

16. Rees D. and T.J. Fuller-Rowell. Thermospheric response and feedback to magnetospheric forcing. Proceedings of the International Conference on Auroral Physics, Cambridge, July 11-15, 1988.

17. Fuller-Rowell T.J. and D. Rees. Invited paper: Modelling of the Thermosphere and Ionosphere, presented in an International Meeting held in Moscow, Jan 1989.

18. Rees D. Dynamics of the Middle and Upper Atmosphere: Existing Knowledge and the Observational Possibilities for the next Decade. Invited paper presented at ESA / ESTEC, May 1989.

19. Batten S and D. Rees. Thermospheric winds in the auroral oval: Observations of small scale structures and rapid fluctuations by Doppler Imaging System. Planetary and Space Science, (in press) 1990.

20. Aruliah A.L., D. Rees and T.J. Fuller-Rowell. The Combined Effect of Solar and Geomagnetic Activity on High Latitude Thermospheric Neutral Winds: Part 1: Observations, J. Atmos. Terr. Phys. Special Issue, 1990, proceeding of the IAGA meeting in Exeter, July 1989.

21. Rees D., S. Batten, A. Aruliah, T.J. Fuller-Rowell, A.D. Farmer and K. Freeman. Long Lived Polar Thermospheric Vortices: A Combined Radar and Optical Studies, J. Atmos. Terr. Phys. Special Issue, 1990, proceeding of the IAGA meeting in Exeter, July 1989.

22. Rees D., I. McWhirter, A.L. Aruliah and S. Batten. Upper Atmospheric Wind and Temperature Measurements using Imaging Fabry-Perot Interferometers, Prepared for the WITS Handbook, September 1989 (pub 1990).

## ANNEX 1.

## SUMMARY OF RELEVANT WORK ON MIDDLE AND UPPER ATMOSPHERE TIDES USING THE UCL MODEL

Coupling of tides generated within the troposphere, stratosphere and mesosphere and interacting with the in-situ solar tides and the results of geomagnetic forcing of the thermosphere has been simulated within the UCL 3-dimensional time-dependent model of the thermosphere via the introduction of tidal forcing near the lower boundary of the existing coupled ionosphere - thermosphere model (80 km).

The present UCL coupled model thus has been used to simulate the amplitudes, phases and height structure of the combined tides in the thermosphere. With appropriate tuning of the tidal sources, results obtained are in reasonable agreement with tidal wind observations at low, mid and high latitudes.

The influence of propagating tides on the thermosphere has been studied for varying background conditions, as a function of latitude, season, solar activity and geomagnetic activity. The significant interactions between propagating and in-situ thermospheric tides and between different propagating tidal modes have also been investigated. Some of these interactions are because of the inherent non-linear coupling of various tidal modes within the mesosphere and lower thermosphere. under other conditions, it is the presence of the ionosphere which leads to non-linear behaviour and tidal mode coupling.

We have recognised from the difficulty of fitting widely different sets of tidal wind data with a single description of the source (represented by a geopotential variation introduced near 90 km altitude) that large variations in the propagation conditions and characteristics within the stratosphere and mesosphere probably occur. Such changes can affect considerably the amplitudes and phases of the propagating tides well before they reach the lower thermosphere. The effects of such changes on the lower thermospheric winds have been simulated by varying the input amplitude and phase of tidal forcing near the existing lower boundary of the thermosphere model.

All of these simulations of propagating tides have used, for the first time, a fully-coupled ionosphere-thermosphere model. In this model, all of the momentum, chemical and dynamical interactions between the ionised and neutral components are included have been modelled in a self-consistent manner, something which has not been possible in previously modelling attempts (Forbes and NCAR). Naturally, the momentum interchange effects are strongest in the geomagnetic polar regions, however, important effects from the point of view of tidal coupling occur at all latitudes.

The relative importance of geomagnetic and tidal forcing mechanisms at high latitudes has already been investigated using this coupled model. The results of model simulations at high latitude have been compared with observations which have only recently become available from the EISCAT incoherent scatter radar facility.

The (1,1) diurnal propagating tidal mode, which is important in the lower thermosphere, has also been simulated for the first time in any three-dimensional time-dependent thermospheric model. This work has, of course, used the coupled ionosphere-thermosphere model, which is also a first. The existence of interactions between the diurnal and semidiurnal tides have also been demonstrated within the UCL model

The interactions of propagating tides with the zonally-averaged flow have also been studied. The dissipation of propagating tides has been shown to produce strong zonal accelerations. Such zonal accelerations have previously been found in models of gravity wave dissipation. The relative importance of different dissipation mechanisms for propagating tides as a function of height have also been investigated within the UCL model.

Recently, we have obtained some fascinating data on tides within the mesosphere from the new Fabry-Perot interferometer observing hydroxyl Meinel band emissions at Utah State University. These data, which show very large (50 $ms^{-1}$) semidiurnal tides, some excelient examples of gravity waves, and occasional very large wind disturbances, provide many challenges.

OUTLINE PROPOSAL FOR FURTHER DEVELOPMENT:

In response to these challenges, we are currently seeking the resources for additional development of the coupled ionosphere - thermosphere model:

i). To decrease the altitude of the lower boundary of the coupled model to 40 km;
ii) To introduce self-consistent geopotential variations just above the 40 km lower boundary to simulate self-consistent tidal forcing of the entire mesosphere and thermosphere (above 60 - 65 km);
iii) To develop a comparable scheme for self-consistent introduction of gravity waves and other disturbances comparable to those we are currently observing with the UCL / USU FPI at Hardware Ranch;
iv) To introduce self-consistent geopotential forcing near the new lower boundary to simulate the effects of Planetary wave structures of the mesosphere.

It is clear that the tidal and gravity waves which are observed cannot be adequately simulated by assuming that the propagation characteristics within the upper stratosphere and mesosphere are always unchanged. Thus there is the challenge to handle that variability in a fully self-consistent fashion. The fabric and structure of the UCL coupled model is designed for such adaptation, and we are seeking the additional manpower resources to aid us accomplish that task.